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THE CORRELATION BETWEEN THE BUTTER-FAT PERCENTAGE OF ONE LACTATION AND SUCCEEDING LACTATIONS IN JERSEY CATTLE

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THE CORRELATION BETWEEN THE BUTTER-FAT PERCENTAGE OF ONE LACTATION AND THE BUTTER-FAT PERCENTAGE OF SUCCEEDING LACTATIONS IN JERSEY CATTLE*

By John W. Gowen.

SUMMARY

This bulletin presents a study of the accuracy with which the butter-fat percentage of one lactation predicts the butter-fat percentage of a subsequent lactation for a pure bred herd of Jerseys under uniform farm conditions. The correlation coefficients describing this relation range from $+0.6781 \pm .0310$ to $+0.2470 \pm .0640$. The numerical value of these correlation coefficients signifies that with a fair degree of accuracy the butter-fat percentage of one lactation measures the probable butter-fat percentage of a subsequent lactation.

The mean of these correlation coefficients for butter-fat percentage of one lactation with another was +0.5215. The mean of the milk production of one lactation with another was +0.5352. There is consequently no difference in the relative accuracy of the prediction of milk yield or butter-fat percentage from one lactation to another.

The mean value of the correlation coefficients for the monthly egg yield of White Leghorn pullets with their year egg yield was +0.446. Comparison of this correlation with those given above makes it seem that greater dependence may be placed in the record for milk yield or butter-fat percentage of a cow as a measure of future production than can be placed

*This paper is an abstract of a longer paper on "Studies in Milk Secretion VI. On the Variations and Correlations of Butter-Fat Percentage with Age in Jersey Cattle," published by the same author in Genetic, May 1920. All literature citations should be made to this complete paper.

in the monthly egg record of a hen as a measure of her year record.

The relation of the average butter-fat percentage of one lactation with the butter-fat percentage of five lactations is determined. These correlation coefficients range from +0.784 ±.028 to 0.862±.018. Such high values indicate that with slight inaccuracy the butter-fat percentage of one lactation predicts the butter-fat percentage of the first five lactations of a cow's life.

Table 4 furnishes a ready means of determining from the butter-fat percentage of the first lactation what the butter-fat percentage of the first five will be for a Jersey herd of similar butter-fat percentage to the herd here studied.

In a preceding bulletin the discussion of these data was directed toward the analysis of the influence of age on the percentage of butter-fat produced in a given lactation and the variability of this butter-fat percentage with age. In the present bulletin the phase of the problem dealing with butter-fat percentage of one lactation in relation to that of another lactation will be considered.

Little or no analysis based on concrete data has been made on this problem, yet obviously on a knowledge of these relations depend the justification for many of the practices now extant in dairy husbandry as well as laying the foundation for the solution of many problems connected with the secretion of butter-fat percentage itself. The existing information concerning butter-fat secretion is largely empirical. It is commonly said that the great butter-fat producing machines of today are due to these cattle breeders using such methods. In the widest sense this is no doubt true although such a mode of procedure tells us nothing about the biological factors underlying the advance in butter-fat percentage, or the laws by which it is governed. In such cases chance and luck play a very important part in the improvement. It is in the removal of these disturbing factors and making the improvement less haphazard that exact numerical analysis find their place. The solution of the problems connected with butter-fat production are complex and need to be approached from many angles. This section of the present investigation was undertaken in the hope that some knowledge of the intra-individual variation with regard to the relative concentration of this butter-fat from lactation to lactation would throw some definite light on these problems. The homogeneous nature of the material is especially favorable to this problem.

Naturally the problem resolves itself into a study of the relative strength and precision of action of the inherited complex possessed by the cow working in conjunction with and in opposition to the environmental changes. If heredity plays a large part in the production of a cow the position of the cow in the frequency curves discussed in the earlier part of the paper will remain approximately the same from lactation to lactation; if on the other hand heredity of butter-fat production is weak in comparison with the influence of the shifts in environment, the position in our frequency curves of the cow will change materially from lactation to lactation. The preliminary steps in the analysis of this problem included a study of the mean butter-fat percentage for each age and the standard deviations of this for the different ages.

The conclusion which may be drawn from this study of the means, standard deviations and coefficients of variation is that no selection of cows for future milkers on the basis of their butter-fat percentage in previous lactations has been practiced at any time in the herd's history. This important conclusion regarding the data reflects back on the conclusion drawn from the studies of the earlier paper* as those conclusions are freed from the one possible criticism that selection of the best producing animals, to be kept for the milkers in later life, by the records made while they were young, has materially influenced the general applicability of the results of this study to the herd of Jersey Cattle as a whole.

The Correlation of the Butter-Fat Percentage for Eight Months' Milk Yield at a Given Age With the Like Butter-Fat Percentage at any Other Given Age.

The homogeneous nature of the records established by the previous analysis, the data may now be used for the correlations

*Gowen, John W., 1920. The Variation of Butter-Fat Percentage with Age in Jersey Cattle. In Annual Report of the Maine Agricultural Experiment Station for 1920. pp. 132-144.

themselves knowing that the data on which these correlations are based are such that the values of the correlations are their true values.

TABLE 1.

Coefficients of Correlation for Butter-Fat Per cent of a Given Year when Correlated with Other Given Years.

AGE CORRELATED.

Age with which correlated	2:0—3:0	3:0—4:0	4:0—5:0	5:0—6:0
2:0—3:0	--------------	+0.5277±.0368	+0.5288±.0390	+0.5846±.0382
3:0—4:0	+0.5277±.0368	--------------	+0.6071±.0349	+0.5836±.0384
4:0—5:0	+0.5288±.0390	+0.6071±.0349	--------------	+0.6781±.0310
5:0—6:0	+0.5846±.0382	+0.5836±.0384	+0.6781±.0310	--------------
6:0—7:0	+0.5956±.0407	+0.5861±.0426	+0.5236±.0460	+0.5529±.0417
7:0—8:0	+0.6068±.0452	+0.2470±.0640	+0.5668±.0447	+0.4830±.0480
8:0—10:0	+0.5695±.0468	+0.4311±.0533	+0.4475±.0498	+0.5638±.0382
10:0 and above	+0.5739±.0787	+0.5250±.1121	+0.5163±.0674	+0.4138±.0747

Age with which correlated	6:0—7:0	7:0—8:0	8:0—10:0	10:0 and above
2:0—3:0	+0.5956±.0407	+0.6068±.0452	+0.5695±.0468	+0.5739±.0787
3:0—4:0	+0.5861±.0426	+0.2470±.0640	+0.4311±.0533	+0.5250±.1121
4:0—5:0	+0.5236±.0460	+0.5668±.0447	+0.4475±.0498	+0.5163±.0674
5:0—6:0	+0.5529±.0417	+0.4830±.0480	+0.5638±.0382	+0.4138±.0747
6:0—7:0	--------------	+0.5594±.0420	+0.4678±.0434	+0.3196±.0788
7:0—8:0	+0.5594±.0420	--------------	+0.6004±.0349	+0.4137±.0659
8:0—10:0	+0.4678±.0434	+0.6004±.0349	--------------	+0.5294±.0436
10:0 and above	+0.3196±.0788	+0.4137±.0659	+0.5294±.0436	--------------

Table 1 gives the correlations and their probable errors for all ages at which the lactation records were divided. The vertical columns as in the preceding tables for the other constants of the correlation surfaces give the correlations of the butter-fat percentage of the ages heading the column with the butter-fat percentage at the ages indicated on the left hand margin of the table. As will be noted the correlations necessary to give the complete set of correlations for any age are repeated e. g. the correlation of 2 years butter-fat percentage with that at 3 years is $+0.5277 \pm .0368$ and appears in the two year column on line with the three year age. The correlation of the three years butter-fat percentage with that of the two years will, of course, be the same (0.5277±.0368) and is repeated in the three year column on the line with the two year age. Such an arrangement facilitates the grasping of the complete picture of the relation between the yield of a given age and that of any other year, as each column represents the correlation coefficients of that year with the other years.

The largest of these correlation coefficients for the butter-fat percentage of one lactation in comparison with that of another is +0.6781±.0310 for the lactation at four years old and at five years old. The lowest correlation coefficient is +0.2470 ±.0640 for the comparison of the butter-fat percentage of the three year olds with that of the seven year olds. All of these correlations are plus. There was no correlation out of the fifty-six determined which was not significant. Such high correlations point to a regulatory mechanism behind the mammary function which governs, within certain limits, the concentration of butter-fat which a given cow is able to secrete into her milk from one lactation to another. In other words the correlations of butter-fat percentage of a given aged cow with that of the other ages at which this cow may have other lactation records are approximately of the same values throughout.

The average level of the correlations for butter-fat percentage of a lactation of a given age with those at any other age is of especial interest to the dairyman since the size of the correlation is the index by which he may choose the lactation on which to base the selection of animals to remain in the herd as future milkers. The averages of these correlations have accordingly been made. The highest average correlation coefficient is for the butter-fat percentage of the lactation commencing between the ages two years to three years (0.5696). The next highest average correlation coefficient is for the four year age (0.5520). The five year ages is third (0.5514), the eight and nine year age is fourth (0.5156). The other ages at lactation follow in the order, six, three, seven, and ten and older years. The differences in these correlations are of only doubtful significance so that no conclusion as to the relative merit of the use of one lactation over that of another as a basis for selection of animals to remain in the herd, can with certainty be made. Further from the theoretical side no conclusion can be drawn from these figures as to any differential action of the mechanism or effect of environment on the milk production and butter-fat percentage at these different ages. They do, however, lead to the important practical conclusion that a cow commencing her lactations as a two year old with a high butter-fat percentage may be expected to duplicate this relatively high performance within a small error in the next and succeeding lactations. The first lactation records as to the butter-fat percentage that a given cow will produce, are a good index of what may be expected in future years of that cow, as will be shown in a subsequent section. The selection of cows to remain in the herd on the basis of these records is profitable to the dairyman.

The comparison of these correlations with those on milk production for the same date using the same divisions is of considerable interest as showing the relative strength by which one lactation governs the future production of another lactation. Table 2 gives this comparison for the average unweighted coefficients of correlation for the records of each age with the records made at another age.

TABLE 2.

Average Coefficients of Correlation for Lactation Records Made at a Given Age and Lactation Records Made at Other Ages for Milk Production and Butter-Fat Percentage.

Age at which given record is made	Coefficient of Correlation		Difference Butter-Fat Percentage Milk Production
	Butter-Fat Percentage	Milk Production	
2 years to 3 years	+0.5696	0.5491	.0205
3 years to 4 years	.5011	.5694	—.0683
4 years to 5 years	.5526	.5060	.0466
5 years to 6 years	.5514	.5735	—.0221
6 years to 7 years	.5150	.5661	—.0511
7 years to 8 years	.4967	.5501	—.0534
8 years to 10 years	.5156	.5077	.0079
10 years and older	.4702	.4597	.0105
Average of records at all ages	.5215	.5352	—.0137

These correlation coefficients range in value from +0.4702 to 0.5696 for the butter-fat percentage and from +0.4597 to 0.5694 for the milk production. The average value of the butter-fat percentage correlation coefficients is +0.5215 and the average value of the milk yields is +0.5352.

Of the sixteen average coefficients of correlation four of those for the butter-fat percentage are higher than those for the milk yield and four of them are lower.

The greatest difference of these coefficients is −−0.0683. The difference of the average values is −−.0137. From the numbers involved it seems probable that these differences are so small as not to be significant. Such being the case it follows that the relative accuracy in the use of one lactation record to predict the expected record of another lactation is approximately the same for the butter-fat percentage and for the milk yield. In other words the governing power (presumably the complex given the animal through its inherited factor for these two characters) works with about the same accuracy (as measured by its performance) from lactation to lactation. This by no means would necessarily mean that the inheritance of these two characters is the same. in fact in all probability high milk production is governed more by dominant factors than is high butter-fat percentage. It only means that these factors once given an animal hold it to the same relative level from lactation to lactation.

If we make the point of environment, transfer our reasoning to the race of Jersey Cattle with which we are dealing, these records of the individuals in this race show a distinct differentiation. The high individuals tend to remain high the low individuals low with respect to their butter-fat percentage just as they also do with respect to their quantity of milk. Such a difference can bespeak for but one thing the animals in this race are innately differentiated with regard to their capacity to secrete a high concentration of butter-fat into their milk as well as they are for the capacity to secrete the quantity of milk.

Only one other economic product has been dealt with quantitatively by the correlation method. The correlation coefficients in this case deal with the relation of the monthly egg production to the other eleven months of the year.

The correlations for these ovulation records range from +0.240±.033 to +.573±.023. The range for the correlations of butter-fat percentage is +0.2470±.0680 to +0.6781±.0310. The range in these butter-fat percentage correlations is greater than that for the ovulation records of the White Leghorn hen.

The mean coefficient of correlation for these ovulation records is +0.446. This mean coefficient of correlation is consequently, slightly below that for butter-fat percentage (0.5215) the difference being 0.0755. This difference, on the face of it, would seem to indicate a greater dependence may be placed in the record of the butter-fat percentage of a known lactation as to the future butter-fat percentage in a given cow's milk than can be placed in a knowledge of a month's egg production to determine the future production of the hen. The difference is not great, however, and may not be statistically significant.

CORRELATION BETWEEN THE MEAN BUTTER-FAT PERCENTAGE OF THE FIRST FIVE LACTATIONS AND THE MEAN BUTTER-FAT PERCENTAGE OF THESE INDIVIDUAL LACTATIONS.

Of perhaps even more interest physiologically and practically is the correlations of the butter-fat percentage of one lactation with the butter-fat percentage as determined for a number of lactations. For this purpose certain of the records on which the correlations of Table 1 were based, were chosen for this purpose. These records included the first five lactations for the cow's life. The correlations and other constants for these are given in Table 3.

Table 3 shows that the standard deviation of the butter-fat percentage for the mean of the five lactations in these 88 cows is lower than the standard deviation of these cows for any lactation. The coefficient of variation for the five lactation average butter-fat percentage is consequently lower than the coefficient of variation for the individual lactations. The mean coefficient of variation for the individual lactations is 9.03. This mean value is 1.38 greater than is the coefficient of variation for the five lactation butter-fat percentage. This difference appears to be slightly significant indicating a less variability for the butter-fat percentage over long periods than over a period so short as one lactation.

The correlation coefficients for the relation of the individual lactations butter-fat percentage for the five lactations are all high correlations as the run of correlations for this kind of data go. Compared with the similar data on milk production the average correlations for milk production are ±0.818 and for butter-fat percentage ±0.827. The value of the correlation coefficients are so high in each case that the average milk production or butter-fat percentage over a number of lactations can quite accurately be predicted from the productions obtained for any lactation.

TABLE 3.

Correlations and Constants for Butter-Fat Percentage over a Number of Lactations and the Butter-Fat Percentage for the Individual Lactations.

Age when lactation commenced	Mean Butter-Fat Percentage	Standard Deviation for butter-fat Percentage	Coefficient of Variation of the butter-fat percentage
2 years to 3 years	5.245±.035	0.491±.025	9.35±.46
3 years to 4 years	5.227±.035	.485±.025	9.29±.46
4 years to 5 years	5.291±.036	.502±.026	9.48±.46
5 years to 6 years	5.225±.033	.462±.023	8.83±.46
6 years to 7 years	5.177±.031	.425±.022	8.20±.41
Five lactation butter-fat percentage	5.216±.029	.399±.020	7.65±.39

Age when lactation commenced	Correlation of individual lactation records and the record for the five lactations	Correlation Ratios for individual records and the record of the five lactations	Regression Equations for the five lactation butter-fat percentage as calculated from any of the given lactations
2 years to 3 years	+0.797±.026	0.827±.023	$B_T=1.819+.648b_2$
3 years to 4 years	.836±.022	.855±.019	$B_T=1.621+.688b_3$
4 years to 5 years	.862±.018	.876±.017	$B_T=1.591+.685b_4$
5 years to 6 years	.857±.019	.873±.017	$B_T=1.349+.740b_5$
6 years to 7 years	.784±.028	.815±.024	$B_T=1.406+.736b_6$
Five lactation butter-fat percentage			

If it is admitted that there is a regulatory mechanism controlling the amount of milk produced by a cow in any lactation as it seems that it must be admitted from the evidence of a particular gland for its secretion, etc; then the large size of the correlations indicate clearly that this mechanism is quite accurately working in governing the relative amount of milk a cow will produce from lactation to lactation.

The precision of action of this mechanism for the secretion of butter-fat in a given cow's milk is greater than is the precision of action of the ovary of a hen in secretion of eggs as may be seen from the data of Harris and Blakeslee. For the White

Leghorn pullets the correlation of their monthly productions with their annual production ranges from $+0.373 \pm .030$ to $0.695 \pm .018$. The range of the correlations for butter-fat percentage is $0.784 \pm .028$ to $0.862 \pm .018$. The mean correlation coefficients stand in the relation 0.556 to .827 or 1 to 1.49.

PRACTICAL ASPECTS OF THE CORRELATIONS FOR BUTTER-FAT PERCENTAGE OF ONE LACTATION WITH THE BUTTER-FAT PERCENTAGE OF THE FIRST FIVE LACTATIONS.

As many of these results have a highly practical bearing it may be well to illustrate one of the uses to which they may be put. The question of what animals shall be saved for milk production and the perpetuation of the herd is a constantly recurring one in dairy practice. The correlations just deduced in Table 3 show that the basis of this selection should be the records of the previous lactation. Suppose the herd is composed of 1000 cows which have just completed their first lactation. The equation for this curve

$$y = 17.8901 \left(1 + \frac{x^2}{3.9271}\right)^{-9.6974} e^{5.2895 \,\mathrm{Tan}^{-1} \frac{x}{1.9817}}$$

allows the calculation of the distribution of these one thousand cows as shown in the second column of Table 4. From the eight months butter-fat percentage Table 3 gives the equation to determine the expected mean butter-fat percentage for the first five lactations. The equation is

$$B_T - 1.819 \pm .648 b_2$$

Where B_T is equal to the butter-fat percentage of the first five lactations and b_2 is the butter-fat percentage for the first lactation.

The data may be tabled for most easy reference by summation of the number of cows from both ends of the distribution and tabling the butter-fat percentage. This has been done for Table 4.

TABLE 4.

Actual Butter-Fat Percentage of One Thousand Two Year Old Cows and the Expected Five Lactation Butter-Fat Percentage for any Division of that Herd or per Cow for Any Division of It.

Actual Butter-Fat Percentage	No. of cows with given butter-fat percentage	Expected Butter-Fat Percentage for the first five lactations	No. of cows summed lowest to highest butter-fat percentage	No. of cows summed highest to lowest butter-fat percentage	Expected average butter-fat percentage —lowest to highest	Expected average butter-fat percentage —highest to lowest
3.75—3.85	1	4.281	1	1000	4.28	5.23
3.85—3.95	2	4.346	2	999	4.32	5.23
3.95—4.05	3	4.411	5	998	4.37	5.23
4.05—4.15	5	4.476	10	995	4.42	5.23
4.15—4.25	7	4.541	17	990	4.47	5.24
4.25—4.35	11	4.605	28	983	4.53	5.24
4.35—4.45	17	4.670	45	972	4.58	5.25
4.45—4.55	25	4.735	70	955	4.64	5.26
4.55—4.65	34	4.800	104	930	4.69	5.27
4.65—4.75	45	4.865	149	896	4.74	5.29
4.75—4.85	56	4.929	205	851	4.79	5.31
4.85—4.95	66	4.994	271	795	4.84	5.34
4.95—5.05	75	5.059	345	729	4.89	5.37
5.05—5.15	80	5.124	426	655	4.93	5.41
5.15—5.25	82	5.189	508	574	4.97	5.45
5.25—5.35	80	5.253	588	492	5.01	5.49
5.35—5.45	75	5.318	664	412	5.05	5.54
5.45—5.55	68	5.383	731	336	5.08	5.59
5.55—5.65	59	5.448	790	269	5.11	5.64
5.65—5.75	49	5.513	839	210	5.13	5.69
5.75—5.85	40	5.577	880	161	5.15	5.74
5.85—5.95	32	5.642	911	120	5.17	5.80
5.95—6.05	24	5.707	936	89	5.18	5.86
6.05—6.15	18	5.772	954	64	5.19	5.91
6.15—6.25	14	5.837	968	46	5.20	5.97
6.25—6.35	10	5.901	978	32	5.21	6.02
6.35—6.45	7	5.966	985	22	5.22	6.08
6.45—6.55	5	6.031	990	15	5.22	6.13
6.55—6.65	4	6.096	994	10	5.22	6.18
6.65—6.75	3	6.161	996	6	5.22	6.23
6.75—6.85	2	6.225	998	4	5.23	6.27
6.85—6.95	1	6.290	999	2	5.23	6.32
6.95—7.05	1	6.355	1000	1	5.23	6.35

The first column of the table gives the butter-fat test of the milk produced in the first eight months of lactation for two-year old cows. The second column gives the distribution of a herd of one thousand two year old cows of like constitution to the pure bred Jersey cattle which are being studied. All the calculations have been carried to several decimal places beyond the tabled constants as only by so doing would the results have been more than approximately correct. The third column gives the butter-fat percentage to be expected for the first five lactations milk of cows which have the butter-fat percentage of those shown in the first column.

Noting the expected butter-fat percentage of the highest and lowest tested cows in this column it is seen that those cows which test very low in butter-fat (3.75 to 3.85) in their first lactation on the average increase 0.581 per cent of butter-fat for the milk of their first five lactations; for the highest butter-fat test cow in their two year lactations the butter-fat percentage for their first five lactations is on the average 0.645 per cent of butter-fat lower than is the test for the first lactation test.

The third and fourth columns give the summations of the number of cows from the lowest butter-fat test to the highest and from the highest butter-fat test to the lowest. The last two gives the butter-fat test expected for these one thousand two year old Jersey heifers when the herd is divided at any given place. To illustrate suppose the owner is to cull this herd so that only cows which produced 5.25 per cent of butter-fat in their first lactation will remain in it, what per cent of butter-fat could he expect the remainder of the herd to produce? The answer is found in the last column of the table on the line with the 5.25-5.35 butter-fat percentage of the first column, to be 5.49 per cent. Should it have been desirable to know the butter-fat percentage of the culled section of the herd this is found in the sixth column to be 4.97 on the line with 5.15-5.25 of the first column. The number of individuals remaining in this herd after culling may be seen in the fourth and fifth columns. Since these are tabled for 1000 individuals they may be easily reduced to percentage should it be convenient to deal with the results in this way.

These results are of course only applicable to herds similar to the one being studied. The comparison of the butter-fat test make it seem likely that with only small error these results may be used for the whole of the Jersey breed and possibly the Guernsey breed.

The Mathematical Handling of Breeding Data.

All investigations and inquiries that involve numbers require more or less mathematical handling. Where the data involved are few an arithmetical mean or average is all that is required. For instance in the chemical analysis of a fertilizer rarely more than two or at the outside three determinations are involved. Hence adding these together and dividing by the number of determinations gives the average. On the other hand in plant and animal breeding work where hundreds or even thousands of units of data are involved the handling involves not merely arithmetical but logarithmic methods also and other problems arise than can only be solved by the calculus.

These data that have to be handled in this complicated way and the results that can only be stated mathematically furnish the only sources for the answer to the questions that confront the practical animal and plant breeder. They must be stated in a mathematical form in order to present the results as they exist. The attempt to put them into everyday language impairs their accuracy of definition. The terms used are new and unusual. For the biometrical methods of handling these data are new. In time these will come to be as readily understood as are the terms used in feeding stuffs and fertilizer analyses.

In its publications of the results of biological investigations the Maine Agricultural Experiment Station is embarrassed by just how far the steps in handling the data upon which the conclusions rest should be printed in the papers designed primarily for the men who are at the fore in the practical agriculture of the State. The bulletins of the Maine Agricultural Experiment Station give in black type at the beginning the conclusions arrived at in the publication. The text gives some of the more obvious and more readily comprehended steps in the investigation. The papers sent to the scientific journals go into mathematical handling in much more detail.

With the hope of making the matter of the bulletin clear a sort of dictionary of the terms employed has been prepared and will gladly be sent on request to the undersigned.

Chas. D. Woods, Director
Orono, Maine.